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A GEOLOGICAL EXCURSION IN THE GRAND CAÑON DISTRICT.

BY DOUGLAS WILSON JOHNSON.

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No. 6.—A GEOLOGICAL EXCURSION IN THE GRAND CAÑON DISTRICT.

BY DOUGLAS WILSON JOHNSON.

INTRODUCTION.

THE salient features of the Grand Cañon district have been made familiar by the classic works of Powell and Dutton, and by the more detailed local studies of later observers. An approximately parallel series of north-south faults and folds divides the district into a number of subordinate plateaus, as indicated on the accompanying sketch map (fig. A).

North of the Colorado River the several plateau blocks are called from east to west, the Marble Cañon Platform, the Kaibab Plateau, the Kanab Plateau, the Uinkaret Plateau, and the Shivwits Plateau. South of the river the displacements are less prominent, and have not been carefully traced. Hence a single name, the San Francisco Plateau, is given to this portion of the district.

The name Colorado Plateau has often been applied to this southern area, but such usage leads to confusion, inasmuch as the whole province is known as the Colorado Plateau province. It seems better to follow Powell (**'75**, pp. 186, 195; **'95**, p. 94) in his employment of the name San Francisco for this subdivision of the province. Gilbert (**'75**, p. 47) formally applies the name Colorado Plateau to this area but later speaks of it repeatedly as the San Francisco Plateau (Gilbert, **'75**, pp. 109, 116, 542). Robinson (**'07**, p. 109) has recently defined the limits of this particular subdivision of the plateau province, and employed the name San Francisco to designate it. The name is appropriate, for the district is dominated by the San Francisco Mountain group, of which San Francisco Peak is the highest point, while a large part of the area is included in the San Francisco Forest Reserve. The name Coconino Plateau is generally restricted to the higher portion of the San Francisco Plateau lying south of the Kaibab.

The following notes were made during the summer of 1906 in the course of a wagon trip from Prescott, Arizona, to Salt Lake City, Utah, and are offered as a brief contribution to our knowledge of the physiographic features of the Grand Cañon district.

In the course of this trip we followed along the western side of the Echo Cliffs Monocline for sixty miles, making three traverses across the cliffs to their eastern side. We examined the East Kaibab Monocline for several miles north and south of House Rock Ranch, finally

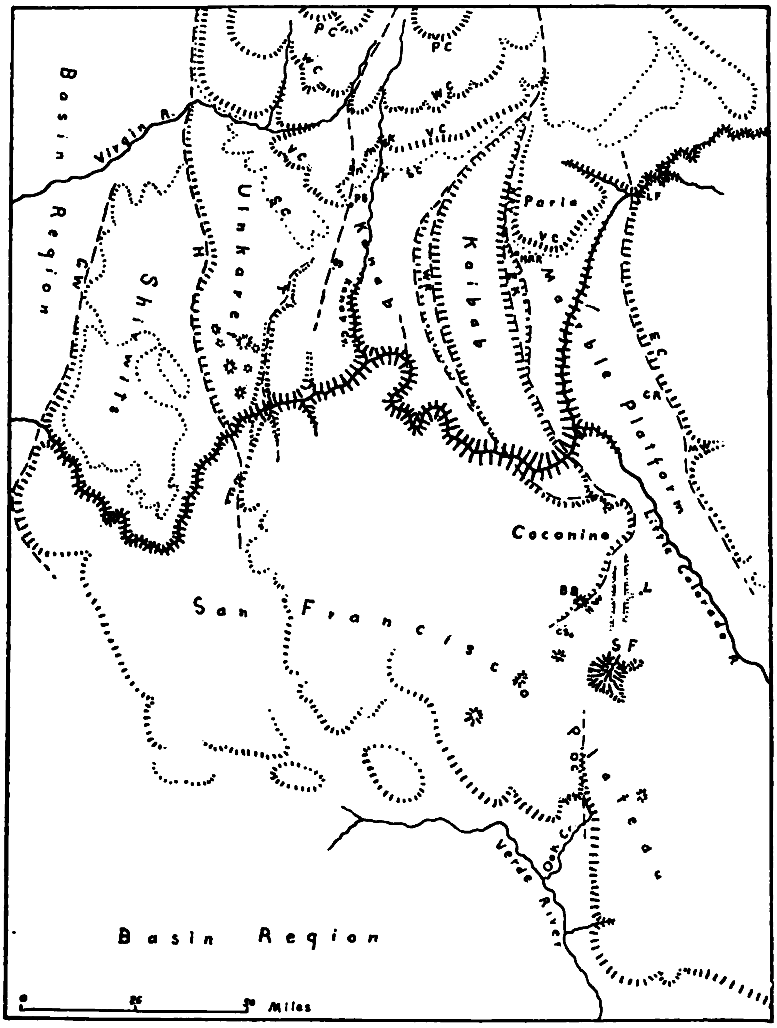


FIG. A.— Sketch map of Grand Cañon district.

passing up over the surface of the great double fold to the summit of the Kaibab Plateau. Passing down Jacob's Cañon we had an opportunity to see the West Kaibab Fault where this cañon opens on the Kanab Plateau at the face of the fault scarp. At Pipe Spring we encountered the Sevier Fault, and followed it southwestward for ten or twelve miles. Turning west, we reached the northern end of the Toroweap Fault and followed it southwest to a point near the Grand Cañon. Returning to Pipe Spring along the Toroweap and Sevier Faults, we next turned westward, crossing the Hurricane Fault near the Arizona-Utah line, and followed it northward into Utah.

In meeting the expenses of the excursion, we were aided by grants from the Massachusetts Institute of Technology and the Sturgis-Hooper fund of Harvard University, and by private contributions from Mr. George H. Crocker, Sr., and other friends of the Institute. Our party included Dr. H. W. Shimer of the Institute, and Mr. C. H. Decker, E. M., of Bingham Cañon, Utah.

It is not necessary to preface these notes with any extensive review of the literature. A short summary of observations made by previous workers in the Grand Cañon district, together with a fairly full bibliography will be found in one of Davis's (**'01**) papers cited below. It is sufficient to note in the present connection that two theories have been entertained regarding the relative ages of the displacements and the main drainage lines of the district. According to Dutton, the courses of the Colorado River and its main tributaries were established before the faults and folds came into existence. The development of the displacements at a much later period was so gradual that these main drainage lines were able to maintain their courses, cutting their channels downward as fast as uplift occurred, wherever barriers were raised across their paths. In other words, the drainage lines are older than the lines of displacement; the Colorado, with its main tributaries, is an antecedent river system. The same conclusion had been reached by Powell (**'75**, p. 198) some years earlier.

An alternative theory has been advanced by Davis (**'01, '03**). According to his interpretation the displacements are much older than supposed by Powell or Dutton. After the displacements occurred, the region was reduced to a peneplain. Across this surface of faint relief the Colorado river system found its way, its course having been determined in part by a series of complex adjustments during the cycle which ended in the peneplanation, while in places the stream courses came to lie across the lines of displacement because the base-levelling process had often reduced hard and soft rocks on the two sides of a displacement to much the same level. Subsequent elevation permitted the river to entrench itself. Weak rock areas were quickly swept away, leaving resistant areas as higher plateaus, the lines of displacement usually marking the boundaries between the two. According to this theory the displacements are older than the river's course. From the standpoint of the present cycle, the Colorado is a structurally superposed river system, having been let down from the surface of the former peneplain.

One object which our party had in view was to test the above theories by personal observation in the field.

FAULTS OF THE SAN FRANCISCO PLATEAU.

Under this heading are briefly considered several fault lines which we encountered on our way across the San Francisco Plateau, from the termination of the plateau in the great escarpment overlooking the valley of the Verde River, to the crossing of the Little Colorado River. These fault lines we could not trace far, nor study carefully, because of limited time. They are of minor importance when compared with the great displacements farther north, but indicate a more strongly faulted condition of the San Francisco Plateau than is usually ascribed to this part of the district.

Our approach to the San Francisco Plateau from the Basin region was by a road which follows up the valley of Oak Creek until near the escarpment; here we entered Bear Wallow Gulch (pl. 17, fig. 1), a small tributary cañon, and made the ascent of the escarpment near the head of the gulch. As seen from the Basin region, the scarp is wonderfully abrupt, and the angular changes in direction of the cliff line suggest the influence of faulting. In the face of the scarp, minor faults are occasionally seen. Bear Wallow Gulch, a tributary to Oak Creek, appears to be developed along a northeast-southwest fault line, and the contact between the Lower Aubrey red beds and the overlying crossbedded sandstone is somewhat higher on the northwest side than on the southeast. The wagon road makes the steep ascent of the escarpment, or the Mogollon Rim as it is locally called, by a series of zigzags, near the head of the gulch. At the first of the westernmost bends in the road the red beds are seen dipping steeply to the southwest where they are dragged up along a fault plane. Farther up, the grey crossbedded sandstone is similarly affected. The continuation of this fault toward the southeast is distinctly visible on the southeast wall of the valley, where the lava capping the crossbedded sandstone abuts against the sandstone at the contact, indicating a considerable displacement. It would appear that the general trend of the displacement where it crosses Oak Creek is northwest-southeast.

From the first western bend in the road, above referred to, one has a splendid view of a prominent fault in one of the outlying mesas (pl. 17, fig. 2, *F*), where the lava-capped crossbedded sandstone on the eastern side of the displacement has dropped down 800 or 1,000 feet (estimated). This fault (which appears to be independent of the one just described) has a north-south trend and coincides with Oak Creek for an unknown distance northward, and may be called the Oak Creek Fault (fig. A, *O. C.*). The eastern side of Oak Creek is thus distinctly lower than the western side. Near the outlying mesa, however, the creek swings to the east of the fault line, leaving a fragment of the downfaulted block west of the creek, and affording the precise contact visible in the end of the mesa. It is evident that the lava is older than the faulting, and from the character of the contact between the lava and underlying sandstone it appears that the lava was outpoured upon a surface at least somewhat diversified, with a valley several hundred feet deep near the present location of Oak Creek.

The topographic features along this portion of the great escarpment terminating the Plateau Province show a fairly pronounced angularity, while segments of the escarpment and portions of the stream courses are relatively straight for considerable distances (see Verde sheet, U. S. topographic atlas). The location of Upper Oak Creek has evidently been determined by the Oak Creek Fault. In like manner, Bear Wallow Gulch appears to have been eroded along a fault line. There is thus a suggestion that faulting has exerted an important control over erosion in this region. More field work will be necessary before the evidence in favor of general fault-control can be regarded as conclusive.

In the vicinity of Oak Creek the beds of the plateau series dip gently northward, thus preserving the general dip observed in other parts of the San Francisco Plateau. Farther north the dip has carried the crossbedded sandstone below the surface, and the overlying Aubrey limestones constitute the upper member of the sedimentary series. The surface remains fairly uniform, so far as we could judge, and it is for the most part covered by basalt flows (whose appearance indicates that they should be classed with the recent rather than with the ancient basaltic outpourings recognized elsewhere in the Plateau region). These relations suggest a peneplain surface bevelling the underlying inclined sediments and covered with sheets of lava. Robinson ('07, p. 109–129) has recently presented evidence from other localities pointing to the same conclusion. The displacement of the lava along the Oak Creek Fault indicates a relatively recent date for the fault, and it is probably correlated in time with the more recent movements along the Hurricane Ledge in the vicinity of the Virgin River, described below.

From Cedar Spring, (fig. A, *C. S.*) northwest of San Francisco Mountain, a broad valley or wash, known as Hull Wash (fig. A, *H. W.*) runs northeast to the Little Colorado. The northwestern side of this wash is bounded by a rather prominent line of cliffs. For long distances the cliff-line is remarkably straight, and small valleys often debouch from the face of the cliffs into the broad wash through sharply cut V-shaped openings, rather than by gradually widening valley mouths. It is believed that the cliffs have been developed along a fault line trending northeast-southwest. Baker's Butte (fig. A, *B. B.*), a volcano six miles northeast of Cedar Spring, was apparently formed across the line of displacement.

A short distance west of Lockett's Tank (fig. A, *L.*) there is a north-south line of cliffs several miles in extent, due either to a faulting movement that dropped the area west of the fault line, or to erosion on a faulted mass. The face of the cliff is of lava, as is also the floor of the valley just west. But limestone appears a short distance back of the cliff face. No time was available for careful study, but the features seemed to indicate that a broad north and south valley, possibly related to an early fault line, had been floored with lava, while a recent uplift along the eastern side of the valley had developed the west-facing scarp. A narrow gorge passes from the broad valley eastward through the scarp. Lava flowed through this gorge, and for several miles along its continuation eastward across the plateau. Much of the lava has been removed from the eastern part of this channel,, but toward its western end the lava is still in place in the bottom of the gorge. Lockett's Tank is a pool developed where the run-off from occasional heavy rains drops from the surface of the lava down to the bottom of the limestone gorge from which the lava has been largely removed (Davis, '01, fig. 13).

A few miles farther west is another north and south line of cliffs, developed in limestone, and dissected by small ravines which open on steep alluvial cones well up the face of the cliff. This line of cliffs faces east, and forms the west side of a valley which has less regular limestone cliffs, of less altitude, on its eastern side. The relations suggest a north-south fault with a downthrow toward the east. Toward the northern end of the east-facing scarp there is a low hill in front of the cliffs which seems to be a down-faulted block. Toward the southern end a side valley from the west enters through the cliffs. From this side valley lava has entered the main valley and floored it with igneous rock in very recent geological time. Lava has also entered the main valley through shallow ravines cut in the face of the cliffs. The amount of displacement in both of these north-south faults is small.

If our observations are correctly interpreted, there are displacements south of the Grand Cañon in greater number than has generally been supposed, but less extensive and much more irregularly developed than the great displacements north of the Cañon. Careful field work will be necessary before the detailed relations can be ascertained.

ECHO CLIFFS MONOCLINE.

Of our observations along the Echo Cliffs Monocline, only those which bear on the origin of the peculiar form of certain parts of the cliffs need be noted here. Brief mention, however, may be made of the remarkable landslides which begin toward the northern end of the cliffs and continue around the base of the Paria Plateau to House Rock Valley, a distance of some fifty miles (pl. 18, fig. 1). These landslides have been described by Davis ('01, p. 121–126) who believes them to be the result of a revival of erosive activity following the uplift of the region which permitted the incision of the present Cañon. We did not observe the slides until we reached a point south of Bitter Spring, where a branch of the Colorado River first reaches eastward to the foot of the cliffs. The sudden development of landslide topography at this point is in accordance with the interpretation quoted above.

As seen in profile the Echo Cliffs Monocline frequently exhibits an eastern slope which is almost if not quite as steep as the bold west-facing scarp; as seen from the west the crest-line of the cliffs is serrate, a succession of sharp peaks or crags, with intervening sags. This departure from the normal tabular form of the cliffs is very striking, and has been mentioned by Powell, Dutton, and Davis. Powell (**'75**, p. 192) relates the peculiar form of the cliffs to the "line of displacement" in a general way; Dutton (**'82**, p. 205) considers it the effect of "the considerable inclination of the strata"; but Davis (**'01**, p. 141–142) suggests that "strike faults with small throw, torn on the slope of the monocline," may be responsible for the features observed. As has been shown by Davis, the character of the cliffs is not due to local increase in the dip of the strata, nor to changes in the thickness of the cliff-making sandstones.

In order to determine whether the back slope of the monocline was cut by longitudinal faults which might account for the oversteepening, I crossed to the eastern side of the cliffs at three points: first, at a point eight miles north of Willow Spring, later at a point a mile or two southeast of Cottonwood Tank, and finally at a point five or six miles south of Bitter Spring. At the two first points the peculiar feature in question was well marked, while at the place of the third traverse, the back slope of the monocline was more gentle. In no case was any evidence of a fault observed. The sandstone composing the upper part of the cliffs is characterized by very pronounced crossbedding having a prevailing, strong dip to the east and southeast. That part of the eastern slope developed on these beds has an inclination fairly coincident with the angle of crossbedding. Lower parts of the slope, developed on beds which show crossbedding but slightly inclined, have a more gentle inclination. Many smaller pinnacles or hills formed from the upper beds have a sharply inclined eastern face undoubtedly developed on one of the steep crossbedding planes, while the pronounced jagged or saw-toothed profile of some of the small ridges seems to be traceable to the influence of the same planes of weakness. At the northernmost section, where the oversteepening of the back slope is not marked, the crossbedding seemed less pronounced, and the eastward inclination of the laminae less uniform than usual. Still farther north, notably between Bitter Spring and Echo Peaks, the Echo Cliffs show strongly developed joint structure, such as is also visible in the Vermilion Cliffs on the opposite side of the Colorado. Erosion, guided by this joint structure gives a sharp, pointed form to spurs and pinnacles in the face of the cliffs. At other places we observed evidence of local faulting cutting obliquely across the cliff-line, but these did not seem to be related to the oversteepened slopes. It seemed to us that the influence of the crossbedding and jointing on erosion might account for the peculiar form of the cliffs.

EAST KAIBAB MONOCLINE.

The East Kaibab Monocline (fig. A, *E. K.*) is a great fold which carries the Carboniferous limestone of the Marble Platform upward toward the west to an elevation from 2,500 to 4,000 feet higher, where it forms the surface of the Kaibab Plateau, or "Buckskin Mountains," as the plateau is locally called. The monocline is in part double, and as one views it from the east he can distinctly see the up-arched limestone rising from 1,500 to 2,000 feet above the desert level of the Marble Platform, then continuing westward across a great bench or terrace from two to four miles wide, from the western side of which it rises in another arch to the summit of the plateau. To the north and to the south he can see the lower fold swing gradually westward until it merges with the upper, and the ascent from the Marble Platform to the summit of the Kaibab is made in a single great arch. As a rule the monocline is free from faulting, but several miles south of House Rock Ranch (fig. A, *H. R. R.*) we observed several minor faults, apparently trending with the strike of the fold.

The Kaibab Plateau is higher toward the south than farther north, and it is near the highest part of the plateau that the Colorado River has cut its way through the fold which rises across its path. It is evident that the river could not have acquired such a course under the present surface conditions of the region, and it was partly to account for the river's course at this particular point that Dutton proposed the theory of antecedence. He believed that the river acquired its present course, and removed the Mesozoic beds from much of the district before the fold developed. At a comparatively recent period the great monocline was gradually raised above the river's path, but so slowly that the river was able to cut down as rapidly as the rocks were uplifted, and so to maintain its course. At this same general period the Echo Cliffs Monocline, and the great faults farther west, were believed to have been developed.

As a part of the drainage system of the Colorado which was fully established previous to the period of folding, Dutton cites the House Rock Valley, which follows the eastern base of the Kaibab Monocline along its northern part. "Just at the base of the East Kaibab flexure is House Rock Valley, which once held a river which has long since vanished, though leaving well marked traces of its former action. None of the great displacements which traverse these masses had any existence at that remote epoch" (Dutton, '82, p. 188). The valley, in common with the rest of the main Colorado drainage, was thus considered antecedent to the uplift which developed the monocline. Davis ('01, pp. 153, 157) has interpreted this same valley as one produced by erosion along a belt of weak rocks after the development of the monoclinal uplift. Walcott ('90, pp. 60, 64) cites the flexing of the hard, compact limestones now forming the surface of the monocline, as an evidence that when the folding occurred a considerable thickness of overlying strata must have been present.

The valley is bounded on the west by the Carboniferous limestone which rises in the symmetrical arch of the lower member of the double monocline. Along the southern part of the valley, at least, the arch has not been cut into by the main stream, but everywhere presents the smooth, arched surface of the upper Carboniferous limestone, from the surface of which the soft overlying beds have been washed away. The eastern side of the valley is bounded by erosion cliffs of Triassic sandstone. The monocline does not show the same dip at all points, nor is its base a straight north-south line. On the contrary, the dip is fairly gentle in some places and much steeper in others, while the base of the fold forms a line which curves distinctly toward the east or west in different localities. Along the southern portion of House Rock Valley one of these curves is well marked, concave toward the east. The cliffs on the east side of the valley curve in sympathy with the curved base of the monocline, so that the width of the valley remains fairly constant (fig. B). It seems clear that House Rock Valley has been produced by the erosion of the weak shales between the Triassic sandstone and Carboniferous limestone, after the development of the monoclinal fold had determined the course the valley was to follow.

The small streams which dissect the east-facing slope of the monocline are characterized in their lower courses by steep-sided gorges that open abruptly on the surface of the Marble Platform. In their upper courses these same streams have broadly open, mature valleys. Inasmuch as the geological series cut by the streams is the same in both parts of their courses, there is a suggestion that the upper courses of these streams may have been developed before the lower courses. This would be the case if the upper part of the Kaibab arch were exposed above a baselevel of erosion which bevelled across softer rocks concealing the lower part of the arch. During the baselevelling period mature valleys would develop on the exposed part of the arch. Subsequent uplift would permit the removal of the soft rocks, exposing the lower part of the arch, and allowing the extended portions of the mature streams to cut new gorges in the newly exposed lower portions of the monoclinal slope.

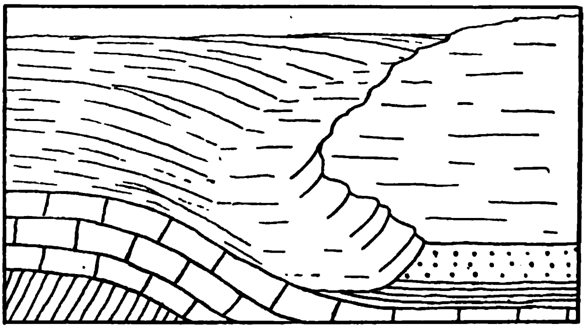


FIG. B.— Diagram illustrating relation of House Rock Valley to curving monocline.

Where we crossed the East Kaibab Monocline on our way to the summit of the Kaibab Plateau, at a point a few miles south of House Rock Ranch, there was a distinct difference in the amount of stream dissection observed in the two parts of the fold. As already described, the lower member of the fold is but little dissected, the surface over large areas arching gracefully with the curve of the rocks, and occasional gorges alone destroying the symmetry of the monocline. When we reached the upper member of the fold, however, we noted a mature dissection of the slope of the monocline; closely spaced ravines, separated by rather sharp-crested divides, have consumed most of the original surface. We made the ascent of the first part of the fold by passing up over the surface of the arch itself, because there is plenty of surface left, and very little room in the bottoms of the gorges which dissect it. In ascending the upper member of the fold, however, we first passed up a fairly mature ravine and then up a dividing ridge, because there was little or none of the original surface left. If this striking contrast in the degree of dissection prevails elsewhere along the double monocline it is a strong indication that after the fold was developed the upper part was subjected to erosion while the lower portion was yet concealed below the overlying baselevelled Permian. Later stripping of the Permian revealed the lower member of the fold, and exposed it to erosion in the next cycle.

Some miles south of House Rock Ranch, at a point where the monocline rapidly steepens its dip with an accompanying westward swinging of the base line, there is found a series of well marked terraces. These terraces bevel across the softer beds which overlie the Carboniferous limestones in the plateau series, slope gently downward toward the east, and are capped by a considerable thickness of alluvium consisting largely of limestone débris. They are now much dissected, but still persist over a considerable area, marking two or three distinct levels; the lowest series extends far out across the platform east of the monocline, and an unknown distance to the south. The higher terraces cover a much more restricted area than the lower series. A small remnant of a similar terrace is found near the foot of the monocline just north of the ranch.

That these terraces mark a baselevel of erosion there can be no doubt. But it is quite possible that they represent a temporary local baselevel, not of great significance in the general history of the region. Their greatest significance lies in their relation to the monocline. According to the antecedent theory, the softer beds overlying the limestone were largely removed from the Marble Platform region before the folding, although occasional remnants remained. The preservation of these remnants could bear no relation to the great monoclinal fold, believed to be developed only after this work of erosion was largely completed. According to the alternative theory, the fold was developed at an earlier period and included the overlying rocks in the up-arching. Subsequent erosion to general or local baselevels would bevel the softer beds east of the monocline and the bevelled surface might be covered by débris brought down from the hard limestone arch which was too resistant to experience rapid reduction. Later erosion would dissect the débris-covered surface, leaving remnants as terraces. These terraces would remain longest near the base of the monocline, where they would be farthest from the main stream lines and covered by the thickest and coarsest débris from the monocline just west. The finding of the terraces near the base of the monocline south of House Rock Ranch adds one more link to the chain of evidence indicating an ancient date for the displacements in the Grand Cañon district.

WEST KAIBAB FAULT.

After traversing the summit of the Kaibab Plateau, where we were impressed by the maturity of the drainage features, a peculiarity discussed at length by other writers, we entered Jacob's Cañon, one of the cañons leading to the Kanab Plateau on the west. The head of this cañon was of mature aspect, wide and open, with graded side slopes. But as we continued downward to the west we entered a narrow gorge cut in the bottom of the broader valley. The change from the more mature to the younger portion of the cañon is well marked. A good road has been built down the gorge, but so active is erosion during wet weather that we found many places badly washed out, and passing with our wagons was difficult.

Continuing down the gorge, we suddenly passed from between the cañon walls, across the West Kaibab Fault (fig. A, *W. K.*) and out upon the Kanab Plateau. Looking back, we obtained the view shown in plate 18, figure 2. The more mature portion of the valley is seen in cross section, with the steeper-sided gorge cut in its rather flat bottom. The gorge is not located in the center of the older valley, but is at this point cut in its southern side.

It is possible that the existence of harder rock at the level of the inner gorge may in part account for its more youthful character. But if this were alone responsible, we should expect the retreat of the overlying beds to take place at the same rate on both sides of the valley, leaving the gorge symmetrically located with reference to the more open upper portion.

The fact that an inner gorge occupies an unsymmetrical position in a more mature valley, suggests that the upper portion of the valley may have been developed with reference to a higher and older base-level on the soft Permian beds west of the fault. Subsequent regional uplift permitted the removal of the soft rocks, and allowed the streams to incise a gorge in the hard rocks in whatever portion of the older valley it happened to be located. The feature might also be explained as the result of an older and a later uplift along the fault line.

SEVIER FAULT.

In common with the other displacements which traverse the Grand Cañon district, the Sevier Fault (fig. A, *S.*) was regarded by Dutton as of recent age. He described this fault as terminating a few miles southwest of Pipe Spring, where the principal topographic evidence of the fault does vanish (Dutton, **'82**, p. 20–21). It was a part of Dutton's theory that the faulting was so very recent that erosion had not yet been able materially to affect the fault cliffs. He writes: "It may be remarked here that every fault in the district is accompanied with a corresponding break in the topography. I do not recall an instance where the lifted beds are planed off by erosion, so as to make a continuous level with the thrown beds" (Dutton, **'82**, p. 130). Yet he recognizes the greater retreat of the plateau terraces on the up-thrown side of the faults as one result of the faulting. Thus, he states that the faults occurred so long ago that the Vermilion and Shinarump Cliffs have been worn back from ten to twenty-five miles on the up-thrown side, in excess of the amount of wearing back on the down-thrown side, since the time of the faulting (Dutton, **'82**, p. 200); also that the faults occurred so recently that the fault cliffs have been worn back but little (Dutton, **'82**, pp. 94, 117, 130). Such a discrepancy in the amount of erosion suffered by the two types of cliffs points strongly to some other interpretation than that given by Dutton.

It has already been shown that the retreat of the Vermilion and Shinarump Cliffs in the Pipe Spring district affords evidence of an ancient date for the Sevier Fault (Davis, **'01**, p. 143–145; **'03**, p. 12–15). It has likewise been shown by the same writer that the drainage in that district is from the down-thrown side of the fault toward the up-thrown, and that cliffs of the down-thrown rocks overlook lower areas eroded on the up-thrown rocks (Davis, **'01**, p. 145–146; **'03**, p. 15–16). A complete reversal of the topographic effects of faulting is thus shown, pointing to an ancient date for the fault, and at least one period of extensive baseleveling between the faulting and the present time. The following paragraphs present similar evidence observed farther southwest, and add another argument for the ancient date of the Sevier Fault.

About seven miles southwest of Pipe Spring is a line of low hills the most prominent of which is called Cedar Knoll. As seen from the west the hills present a more or less pronounced north and south es-

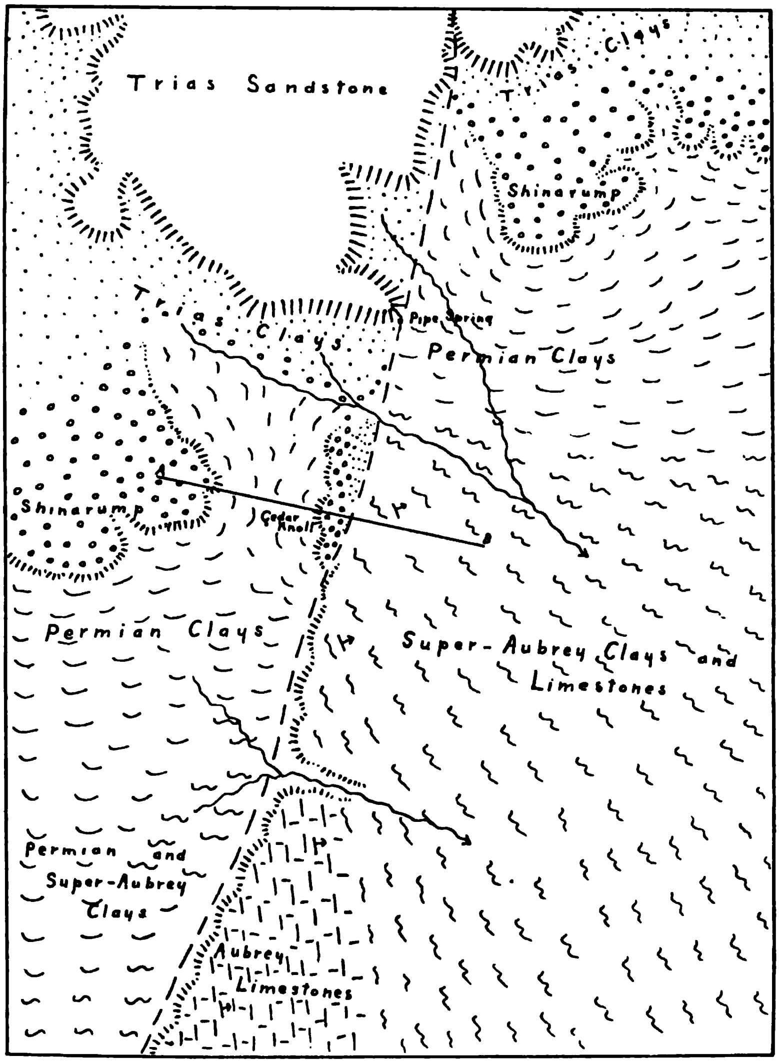


FIG. C.—Geological sketch map showing general relation of beds along Sevier Fault, in the Cedar Knoll – Pipe Spring district.

carpment. To the south the escarpment, with a slight break, continues for a number of miles, being of moderate elevation only, but having lower and lower beds rise to form its face. These west-facing cliffs are about in line with the supposed southward continuation of the Sevier Fault, and would naturally be considered the face of the fault scarp throughout its length. As will appear from the accompanying sketch map (fig. C), however, the portion of the cliff-line forming the west side of Cedar Knoll is an erosion cliff capped by the Shinarump conglomerate; the fault scarp dies out near the point where the erosion scarp appears, because here relatively non-resistant beds form the surface on both sides of the displacement.

The fault is easily detected on the lowland east of Cedar Knoll, where Triassic shales one hundred feet above the Shinarump conglomerate abut against Carboniferous limestone and red shales. Even the transition from the weak red Triassic shales to the more resistant red Carboniferous shales can be readily discerned on close inspection. It will be seen that the beds on the down-throw side of the fault bend downward on approaching the fault, as shown in Cedar Knoll (fig. D), while the beds on the up-throw side are flexed upward in places,—thus conforming to the peculiarity noted elsewhere in the faults of the Grand Cañon district.

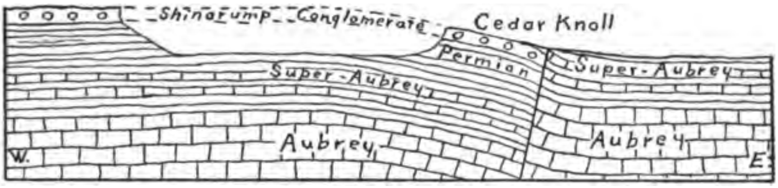


FIG. D.— East-west section along line AB (figure C) showing relation of beds at Sevier Fault, in Cedar Knoll district.

At Cedar Knoll the beds of the downthrown side are higher than and overlook the beds of the upthrown side. In addition to this complete reversal of the topographic expression of faulting, there is an obliteration of all topographic effect of faulting northeast of the knoll, where the beds on both sides of the fault line are weak shales; while southwest of the knoll the cliffs are traversed by a stream channel which drains a large area of the downthrown rocks west of the fault, through a narrow gorge cut in the cliffs, to the upthrown rocks east of the fault.

A dam built across the entrance to the gorge serves to retain a part of the small amount of water which falls in this desert region, forming a pool at which cattle and horses may drink. In common with the reversal of the topographic effect of faulting at the knoll, the absence of cliffs farther northeast, and the drainage relations may be best explained on the basis of an ancient date for the faulting.

As stated in a preceding paragraph, successively lower beds rise in the face of the cliff as the latter is traced toward the southwest. This feature becomes especially noticeable when the upper Carboniferous limestones appear. Bed after bed of this series rises from beneath the general level of the Uinkaret Plateau, to take its part in forming the west-facing escarpment. Yet the escarpment does not show a corresponding increase in height. On the contrary, the beds are bevelled across at a fairly uniform elevation, so that the outcrops of the successive layers swing away from the summit of the scarp, toward the east, as shown in the map (fig. C). Such relations indicate that there has been an uplift accompanied by warping along the east side of the fault, with subsequent baselevelling to reduce the uplifted beds to a fairly uniform surface. The softer beds (upper Carboniferous and lower Permian shales) which the faulting left opposite the limestones on the western side of the fault, have been more or less removed by erosion, so that the surface on the west is now lower, consisting of the Carboniferous limestone series with considerable remnants of the overlying shales. There would seem to be no doubt that we have here to deal with a cliff developed along an ancient fault after a period of more or less extensive baselevelling had once destroyed the original topographic effect of faulting. It has been suggested that such cliffs may be called "fault-line cliffs," to distinguish them from true fault cliffs resulting directly from displacement.

TOROWEAP FAULT.

According to Dutton the Sevier and Toroweap Faults are independent, the first having its southern end near Pipe Spring (fig. A, *P. S.*), the latter its northern end twenty miles north of the Grand Cañon. The faults are therefore represented as distinct on the maps accompanying Dutton's monograph.

Davis recognized that the Sevier Fault continued farther southwest than supposed by Dutton, and concluded that it joined the northern end of the Toroweap Fault, or in other words, that the Sevier and Toroweap Faults were one and the same. He therefore describes the two as a single fault, under the name "Sevier-Toroweap Fault" (Davis '01, p. 143–144; '03, pp. 3, 4, 17–18).

In making our trip from Pipe Spring to the Toroweap Valley we traced the position of the Sevier Fault to a point some miles southwest of Cedar Knoll. Continuing in a more westerly direction, we encountered a low monocline which gradually increased in height as we followed it southwest. Later this monocline gave place to a fault, which we traced practically without interruption into the Toroweap Valley, proving that it was the Toroweap Fault (fig. A, *T.*). We concluded, therefore, that the two faults were independent, and that the Toroweap Fault died out north of the Cañon, as supposed by Dutton; the Sevier Fault, however, continued much farther south than he supposed. Plate 19, figure 1, shows the Toroweap monocline near where we first encountered it, west of the Wild Band Pockets, the displacement at this point being only fifty feet. Climbing to the summit of this low hill, the escarpment of the Sevier Fault could be distinctly seen six or eight miles away, toward the southeast.

In plan, the Toroweap monocline curves quite distinctly, as shown in the sketch map (fig. A). In section it appears as a simple monoclinal fold of gentle inclination toward its northeastern part, where the displacement is of small amount (pl. 19, fig. 1). Still farther northeast the limestones have passed beneath the surface, and the monocline developed in the overlying shales has been planed off by erosion. Its presence can be detected in the dip of the shales as exposed in the gullies near the Wild Band Pockets. Toward the southwest the displacement increases in amount, and the simple monocline changes to a double monoclinal fold, similar to the double portion of the East Kaibab Monocline although on a much smaller scale. How far this double character is maintained we did not ascertain, but it is well shown in a ravine traversing the fold several miles west of Sawyer's Tank. At some point near the head of the Toroweap Valley proper the monocline changes to a fault (pl. 19, fig. 2) which increases in throw toward the south, the displacement amounting to 600 or 700 feet at the Cañon, according to Dutton ('82, p. 93). It is thus certain that the northward decrease in the amount of displacement, described by Dutton, is really present, and that it cannot be explained as an apparent decrease due to the location of the lava flows, as suggested by Davis ('03, p. 20).

Near the head of the Toroweap Valley the beds on the western side of the valley flex downward toward the east, while lower beds on the eastern side of the valley dip in the same direction. The presence of the Toroweap Fault is thus indicated, as well as the fact that the beds of the downthrow flex downward and the beds of the upthrow flex upward as the fault plane is approached, a peculiarity noted repeatedly in the faults of this region. The monoclinal folding which preceded the faulting and determined the direction of the flexing noted, was presumably older than, and distinct from, the westward-facing monocline farther northeast, which is a part of the later fault displacement.

At two places along its course the fold or fault disappears under volcanoes which are built over the zone of displacement, part of the cone being on the upper and part on the lower side. One is a short distance west of Sawyer's Tank, the other near the head of the Toroweap Valley. In neither case does there appear to be any doubt that the displacement visible on either side of the volcanic covering is the same and continuous.

The Toroweap Valley was regarded by Dutton as one of the ancient tributaries to the Colorado whose valleys were carved before the faults developed (Dutton, '82, pp. 94, 99, 201). This interpretation was based in part upon general considerations already referred to and in part upon the fact that the Esplanade (upon which the Toroweap Valley opens and with reference to which level the valley was believed to have been developed) is displaced where the Toroweap Fault crosses it. That the break in the level of the Esplanade does not afford evidence of a recent date for the fault has been pointed out by Davis ('01, pp. 143, 174). In addition to the fact that the valley closely follows the line of displacement, there are two features which indicate an ancient date for the fault.

As in the case of the Sevier Fault, the drainage in the Toroweap area is in part across the displacement, from the downthrown to the upthrown side. Sawyer's Tank is formed by building a dam across a narrow gorge in the monocline, to intercept the drainage, which flows from the low area eroded on the soft rocks of the downthrow side, through the monoclinal uplift, to the upthrown area east of the fold.

That the Toroweap Fault is not a recent development is further indicated by the maturity of the valleys which dissect the uplifted rocks east of the fault line. These side valleys are as thoroughly mature as is the main valley, which is to be expected if the fault is old, and if both main and branch valleys developed simultaneously after a period of baselevelling; but which is incompatible with the idea that the main valley is ancient, the fault recent, and the branch valleys still more recent. A view of one of these side valleys is shown in plate 21, figure 2. It may be contrasted with the young valley shown in plate 20, a valley eroded in the uplifted block along a part of the Hurricane escarpment where the faulting is truly recent.

Hurricane Fault.

Our observations along the Hurricane Fault were for the most part confined to that portion of its course north of the Grand Cañon district, between the High Plateaus and the Great Basin. Such facts as we noted in the Grand Cañon district related to features already described by Davis (**'01**, p. 146–147; **'03**, p. 26–31), and by Huntington and Goldthwait (**'04**), but are in part presented below because they led us to an interpretation which differs in certain details from the conclusions reached by Huntington and Goldthwait.

It has been shown by the authors above mentioned that the "Hurricane Ledge" is in the main a fault-line cliff, developed by erosion of softer beds west of the fault after baselevelling had destroyed the original topographic effect of faulting; but that at a more recent period movement has taken place along part of the fault line, so that the basal portion of the cliffs in the Toquerville district is of true fault cliffs. In other words, a part of the Hurricane scarp is believed to have been exposed by erosion after the occurrence of an ancient fault movement; while part is believed to have been exposed recently as the direct result of a recent fault movement along the same plane.

We recognize that the two fault movements above indicated have occurred, but believe that the features in the vicinity of the Virgin River, as described by Huntington and Goldthwait, and as observed by us in the field, indicate a third period of faulting quite as distinct as the two others.

A few miles south of the Virgin River, a lava-capped butte of Permian shales is found on the very edge of the limestone cliffs of the Hurricane Ledge. This butte, known as Sugar Loaf Mesa, is seen in the distance in plate 22 (fig. 1). According to Huntington and Goldthwait ('04, p. 224–225), the continuation of the lava cap is found at the base of the Ledge, on the downthrow side of the fault, covering *different* (lower) beds from those under the cap in the butte. It is clear from this that there must have been a displacement *before* the lava flow, bringing different rocks opposite each other, followed by baselevelling to reduce the rocks on both sides to a uniform level, over which the lava was spread across the fault line; also a displacement *after* the lava flow, producing the present break of hundreds of feet between the two parts of the flow. These are the two movements along the fault line recognized by Huntington and Goldthwait.

On the face of the limestone cliffs overlooking the downthrow side of the fault, and two to three hundred feet above the base of the cliffs, is a thin strip of lava (pl. 21, fig. 1) which adheres to the rugged cliff face along several miles of the fault, although removed by erosion in places. This lava strip is represented on the geological map by Huntington and Goldthwait, but its significance is not discussed by them. It is probable that they regarded it as a fault splinter broken from the main lava cap when it was downfaulted, in which case it would have no special significance.

The lava strip does not appear to represent a fault splinter, however. Its contact with the limestone back of it is an irregular, igneous contact, produced by the flowing of the liquid lava against the face of the cliff; and wherever a stream valley occurs in the limestone cliffs, the lava strip follows up the valley for some distance. There is no evidence of faulting between the lava and the face of the limestone cliffs. The lava strip was traced far enough south to see that it could have no possible relation to the cap of Sugar Loaf Mesa. The existence of any peculiar warping or splintering of the former lava cap to produce such a relation is thus excluded. The conditions are essentially as represented in the accompanying diagram (fig. E).

As shown by the figure, three faulting movements are necessary to bring about the conditions indicated in the field: (1) the ancient fault, bringing different rocks opposite each other, which were then peneplained and covered by the lava flow *aa'*, as demonstrated by Huntington and Goldthwait; (2) a second fault dropping the rocks west of the fault down to the position indicated by the dotted lines. After considerable erosion of the fault cliffs, a volcano west (?) of the fault poured out a lava flow, *bb'*, which flowed against the cliff base. (3) A third faulting movement, dropping the region west of the fault to its present position, but leaving a thin strip of the later lava adhering to the face of the cliff.

It appears from the foregoing that this part of the Hurricane Cliffs is directly due to the second and third comparatively recent faulting movements, and that the erosion which followed the first faulting reduced the region to a peneplain which was covered by the older lava flow. This lava flow prevented the differential erosion which gave fault-line cliffs along some of the other faults, and along other portions of this same fault. The cliffs in the Virgin River portion of the Hurricane Ledge are then true fault cliffs of much more recent date than the fault-line cliffs we have considered under preceding headings.

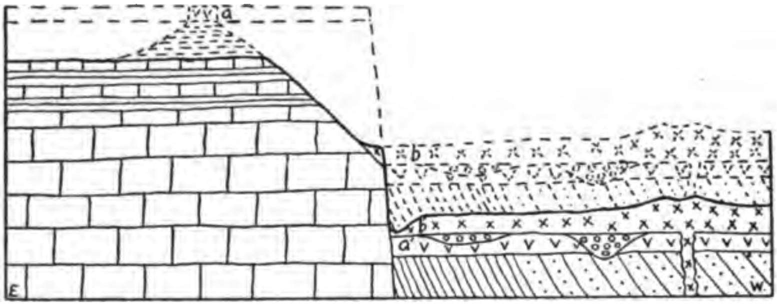


FIG. E.— East-west section through Hurricane Fault, south of Virgin River, showing relation of beds to Sugar Loaf Mesa (farther south), with evidence of three periods of faulting.

If we take into account the monoclinal folding of the plateau series which preceded the first faulting, and ignore the "drag" of the downthrown beds which is strongly developed in the Virgin River section, the succession of events in the geological history of the Hurricane Ledge region of which we are cognizant may be represented by the accompanying rough diagrams (fig. F–M; not drawn to scale).

Since the last faulting there has been sufficient erosion to remove part of the lava strip from the face of the cliff in places, to develop erosion channels in the surface of the flow at the base of the cliffs, and to allow the gorges which open in the face of the cliffs partially to grade their courses, although cascades may be found in the lower, recent parts of the small gorges a short distance back from their mouths (pl. 20).

The facts set forth above require certain modifications of the excellent report by Huntington and Goldthwait. Their geological map (plate 7 of their report) correctly represents the distribution of the lava-capped mesas at the crest of the cliff, the lava strip adhering to the face of the cliff, and the lava at the base of the cliff. But the cross-section E–F on plate 6 of their report, incorrectly represents the strip of lava adhering to the face of the cliff as a fault splinter. Their cross section of this same lava strip where it crosses the Virgin River is correctly shown to lie in its original position against the face of the cliff (fig. 5, p. 225). But they erroneously interpret the strip at this point as being the same as the lava cap of Sugar Loaf Mesa. This accounts for their statement that the recent displacement was but 300 feet at this point, although a displacement of 1,400 feet was noted just south. No attempt is made to explain the manner in which the lava capping the Permian shales at an elevation 1,000 feet higher could have its continuation on the face of the cliff of Carboniferous limestone below. It should be appreciated that figures 4 and 5, placed on opposite pages of their report as illustrating two examples of the same feature ("The first faulting"), really represent different features, separated by a long interval of erosion. The lava caps in the two cases are of different ages, as well as the faults which they cover. The features shown in their figure 4 did formerly exist in the region represented by figure 5, but erosion completely destroyed those features in the latter region; and the close resemblance of the present relations to those which formerly existed should not prevent a full recognition of the significant difference between the two. In figure 5, the lava covering the eastern branch of the fault should be slightly displaced if the conditions are to be accurately represented, as the last faulting movement affected the main fault plane to that extent, although the principal displacement was along a plane just west, in the region of this particular cross section. The 300-feet displacement recorded by Huntington and Goldthwait at the Virgin River represents the movement due to the third faulting only; while the 1,400-feet displacement noted a little farther south represents the movements of both the second and the third faulting periods. The total recent displacement at the two localities is probably about the same.

The baselevelling which followed the first faulting was probably more nearly complete than supposed by Huntington and Goldthwait.

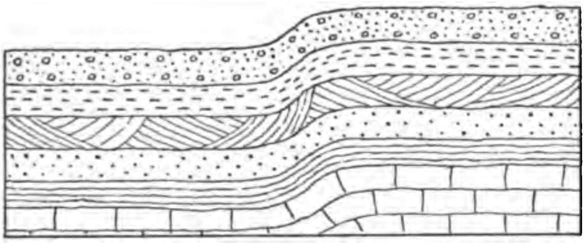


FIG. F.—The folding.

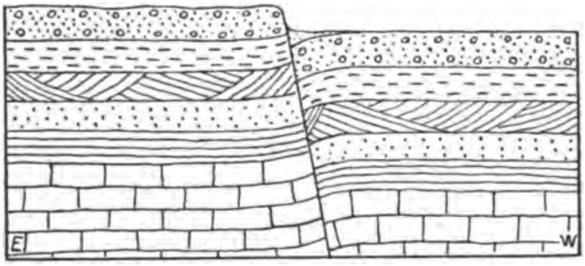


FIG. G.— The first faulting.

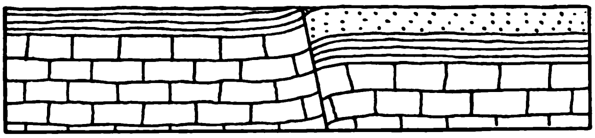


FIG. H.— The great denudation.

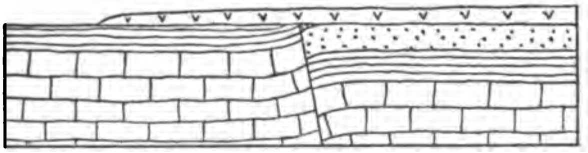


FIG. I.— The first lava flow.

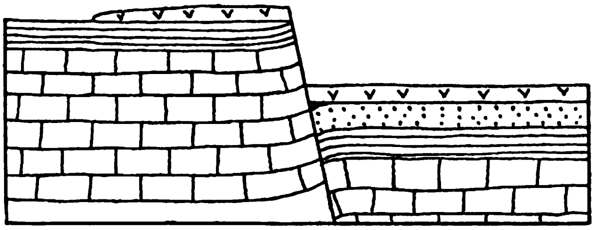


Fig. J.— The second faulting.

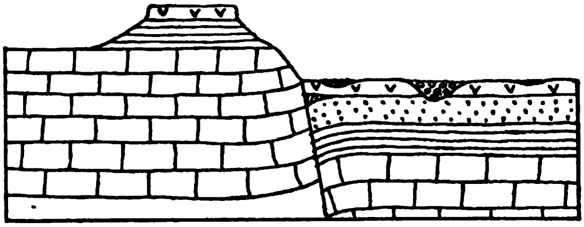


Fig. K.— The second erosion.

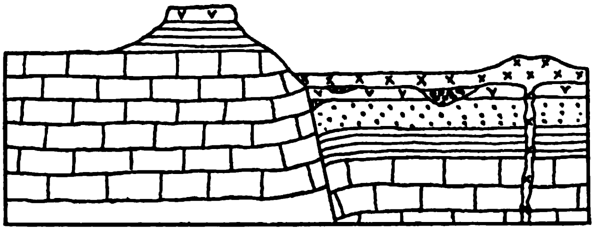


Fig. L.— The second lava flow.

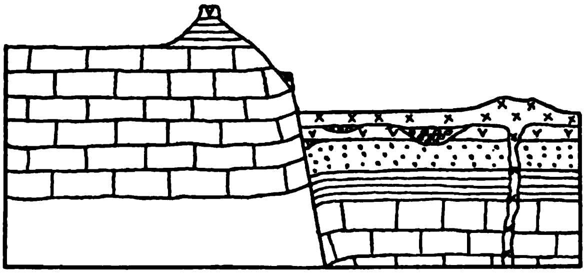


Fig. M.— The third faulting.

They have recognized its completeness farther south, but conclude that in the Virgin River district the baselevelling was not so perfect, since "the lava after crossing the fault was soon checked by an escarpment of limestone rising two or three hundred feet with a fairly strong slope" (Huntington and Goldthwait, '04, p. 230). We have seen, however, that the lava here referred to was the recent flow which followed the second faulting movement, and that the "escarpment" was the one produced by this second faulting, and not one left after the baselevelling period. At the close of that period, the scarp formed by the first faulting was probably as completely obliterated here as elsewhere, the position of the baselevel surface being possibly 1,000 feet higher than the surface covered by the lava flow exposed at the crossing of the Virgin. It appears that this same confusion occurs in the authors' interpretation of the fault north of Toquerville, as three movements instead of two are indicated by the topography along that portion of the fault.

According to our observations the Hurricane Cliffs in the Virgin River district are wholly the result of recent faulting, and represent two different movements separated from each other by an erosion period, and from the first faulting by a long baselevelling period.

SUMMARY.

South of the Cañon, in the San Francisco Plateau, displacements are more numerous than has been supposed, although of little importance compared with the great displacements north of the Cañon. The "crags" of the Echo Cliffs probably owe their peculiar form to erosion guided by strongly marked crossbedding, and possibly in part also to the influence of a well developed system of joints. The Sevier and Toroweap Faults are independent and do not join each other to form one great displacement, as has been thought might be the case. The Hurricane Cliffs in the vicinity of the Virgin River are true fault cliffs wholly due to recent faulting at two different periods. In all, three periods of faulting along the same plane have occurred in that region, the first and second periods being separated from each other by a long era of baselevelling, while the second and third periods were separated by a shorter, but none the less distinct, erosion interval. Observations made along other displacements in the Grand Cañon district confirm the theory that the faults of this district are in the main of ancient date.

REFERENCES.

Davis, W. M.

'01. An excursion to the Grand Canyon of the Colorado. Bull. mus. comp. zool., vol. 38, p. 107–201, 1901.

'03. An excursion to the Plateau Province of Utah and Arizona. Bull. mus. comp. zool., vol. 42, p. 1–50, 1903.

Dutton, C. E.

'82. The Tertiary history of the Grand Canyon district. U. S. geol. surv., monogr. 2, 1882.

Gilbert, G. K.

'75. Report upon the geology of portions of Nevada, Utah, California, and Arizona, examined in the years 1871 and 1872. U. S. geogr. surv. west of 100th mer., vol. 3, p. 21–187, 1875.

Geology of portions of New Mexico and Arizona, explored and surveyed in 1873. *Ibid.*, p. 507–567.

Huntington, E., and Goldthwait, J. W.

'04. The Hurricane Fault in the Toquerville district, Utah. Bull. mus. comp. zool., vol. 42, p. 199–259, 1904.

Powell, J. W.

'75. Exploration of the Colorado River of the West. Washington, 1875.

'95. Physiographic regions of the United States. Nat. geogr. soc., monogr., vol. 1, no. 3, p. 65–100, 1895.

Robinson, H. H.

'07. Tertiary peneplain of the plateau district, and adjacent country, in Arizona and New Mexico. Amer. journ. sci., ser. 4, vol. 24, p. 109–129, 1907.

Walcott, C. D.

'90. Study of a line of displacement in the Grand Cañon of the Colorado, in northern Arizona. Bull. geol. soc. Amer., vol. 1, p. 49–64, 1890.

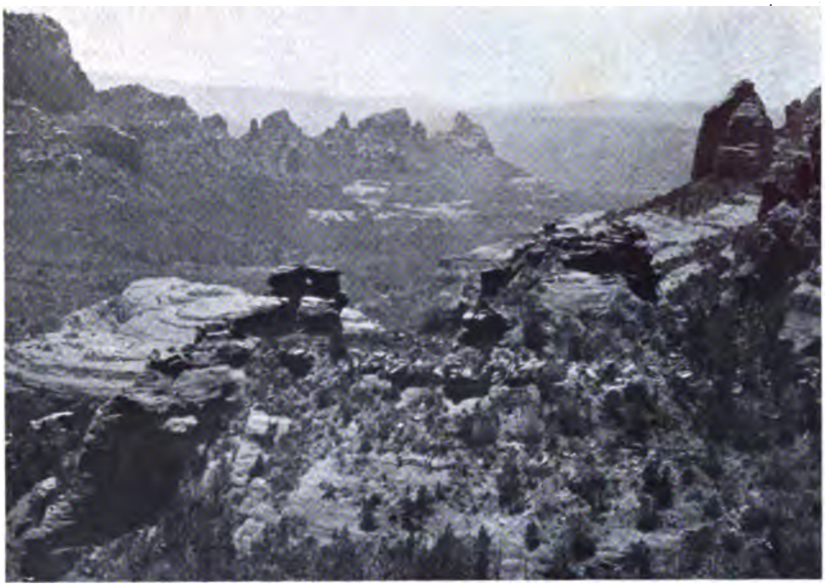
Printed May, 1909.

EXPLANATION OF PLATES

PLATE 17.

Fig. 1. Bear Wallow Gulch, a small cañon in southern edge of San Francisco Plateau.

Fig. 2. Oak Creek Fault (*F*), cutting mesa near Mogollon Rim.



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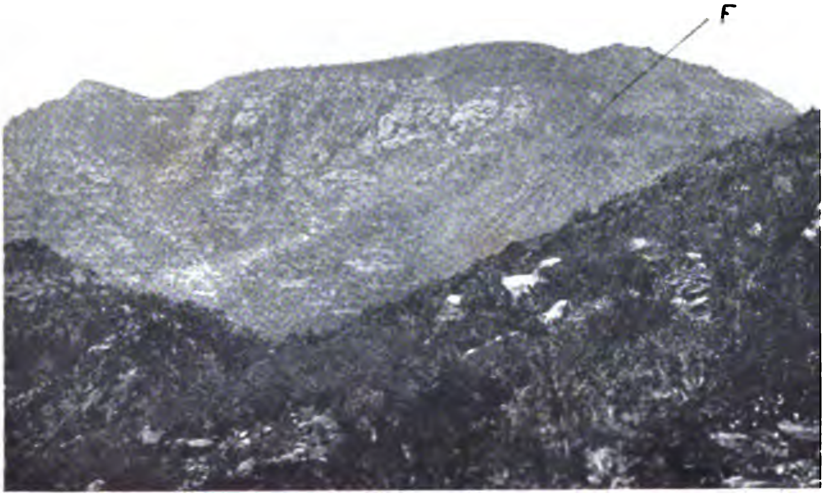

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PLATE 18.

Fig. 1. Landslide at base of Vermilion Cliff, near Jacob's Pool. Photograph by H. W. Shimer.

Fig. 2. Mouth of Jacob's Cañon, at West Kaibab Fault, showing gorge in more mature valley.

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PLATE 19.

Fig. 1. Toroweap Monocline west of Wild Band Pockets.

Fig. 2. Toroweap scarp, east side of Toroweap Valley, a dissected fault-line cliff.

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PLATE 20.

Young valley cut in recently uplifted Carboniferous limestone along Hurricane Fault.

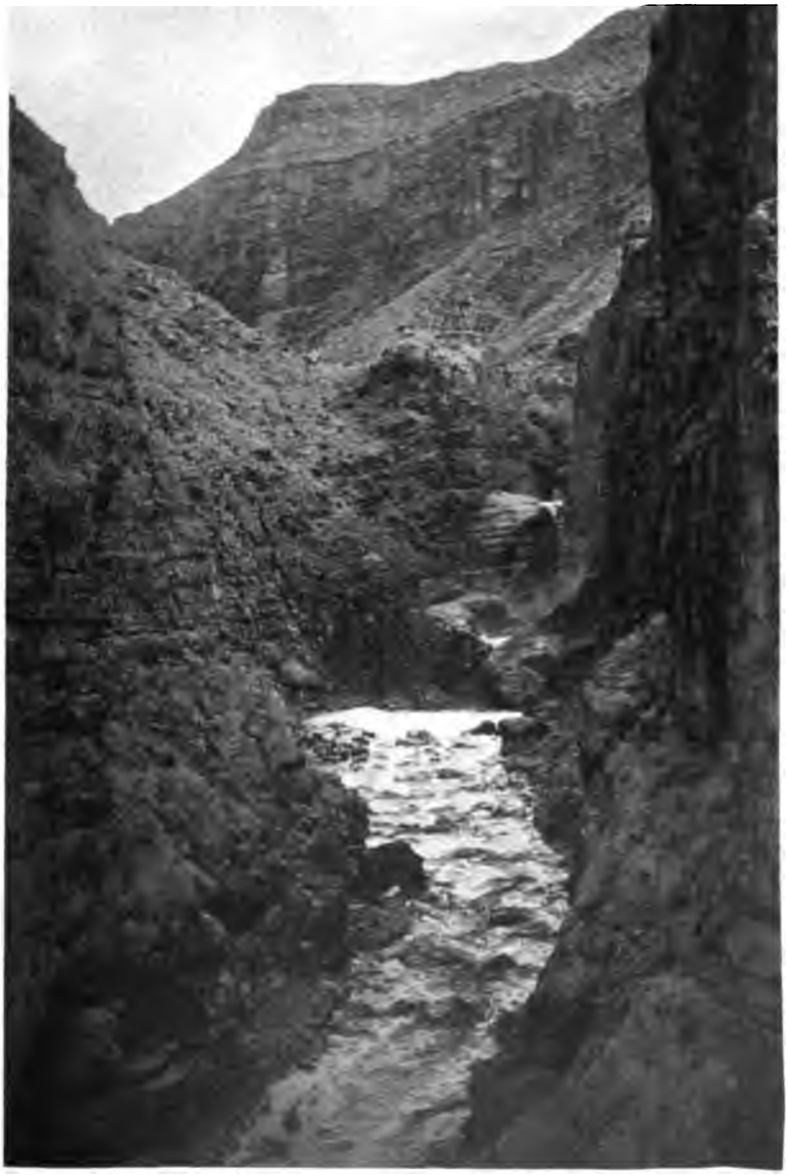

PLATE 21.

Fig. 1. Hurricane Ledge south of Virgin River, showing lava strip adhering to face of scarp.

Fig. 2. Mature branch of Toroweap Valley.

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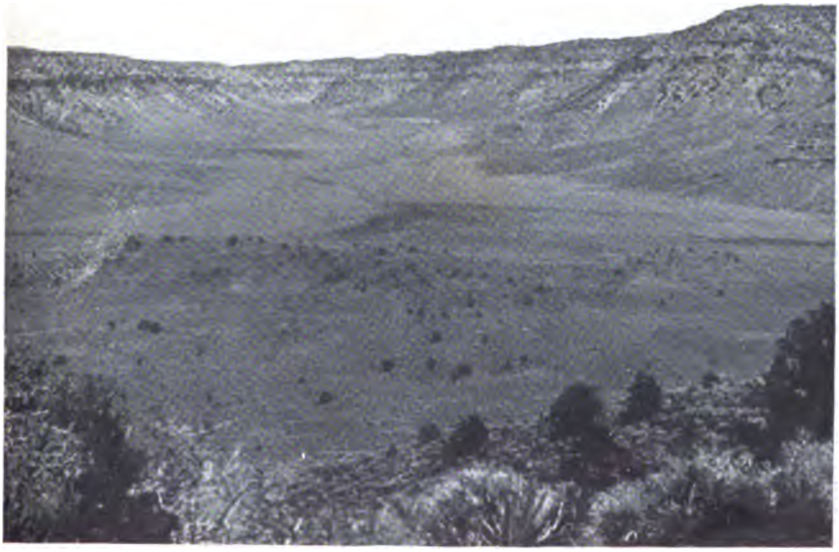

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PLATE 22

Fig. 1. Hurricane Ledge in the Virgin River district; Sugar Loaf Mesa in the distance.

Fig. 2. The Hurricane Fault where it crosses the Virgin River. Horizontal Aubrey limestone on east (upthrown) side of fault, upturned Permian sands and shales on west (downthrown) side.

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